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CdS SOLAR CELLS FOR SPACE APPLICATION

Solid-State Physics Research Laboratory (ARX), ARL

Research at ARL on solar cells started in 1954 as an outgrowth of an in-house program for determining rectifying properties of cadmium sulfide. D. C. Reynolds observed the photovoltaic effect in CdS single crystals about the same time that Bell Laboratories announced the same effect in silicon. In-house research was continued at ARL through 1955, when a contract was awarded to the Harshaw Chemical Company in Cleveland, Ohio to conduct further research and development.

Initial solar cells were bulk CdS crystals having an energy conversion efficiency of about 5% (later improved to 8%), and a maximum power-to-weight ratio of about 10 watts/lb. In 1958, the bulk crystals began to be replaced by solar cells in the form of CdS deposited on a molybdenum substrate. Molybdenum has approximately the same coefficient of expansion as cadmium sulfide, and this property permits the solar cell to maintain its structural integrity throughout extreme changes of temperature. Advantages of film cells over bulk crystals are:

(1) Higher power-to-weight ratio (about 33 watts/lb.)

(2) Mechanical flexibility which permits them to be rolled up into a compact package for launching into space and then extended.

Other materials such as silicon and gallium arsenide have been used successfully in solar cells; however, CdS seems to have the most promise for space application, primarily because of its relative immunity to radiation damage. Electron irradiation tests at Naval Research Laboratory (NRL) in 1962 showed CdS to be at least 1000 times more resistant to electron damage than silicon cells. In September 1963, samples at NRL were irradiated with 1-mev

and 3-mev protons. Under the same radiation dose, silicon cells suffered an 80% depreciation of efficiency; gallium arsenide, 75%; and cadmium sulfide, 2%. Although the cells have not been tested in space, they have been tested under conditions which simulate interplanetary environments. The 3" x 3" Harshaw cells are scheduled for satellite test from Vandenberg AFB sometime this year.

Present CdS film cells have a maximum conversion efficiency of about 5% for a 3" x 3" cell, and about 3% for a 6" x 6" cell. Problems in maintaining homogeneity account for the loss of efficiency with increased size. One individual cell will develop about 1/2 volt under conditions of normal sunlight. Individual cells may be connected in series to increase total voltage for a particular application, or they may be connected in parallel to increase the current output. At the present time, the CdS solar-energy converter appears to be ideally suited to meet the long-recognized need for electrical power for extended periods of time aboard satellites and other space vehicles.

liquid pendulum

Lt. Col. WILLIAM J. BEST, USAF
Geophysics Division, AFOSR

Dr. V. Hugo Benioff of the California Institute of Technology's Seismological Laboratory has recently successfully developed a new liquid-pendulum seismograph. The pendulum in this instrument consists of liquid mercury contained in a long horizontal tube as shown in Fig. 1. The tube is terminated at each end in a closed cylindrical well.

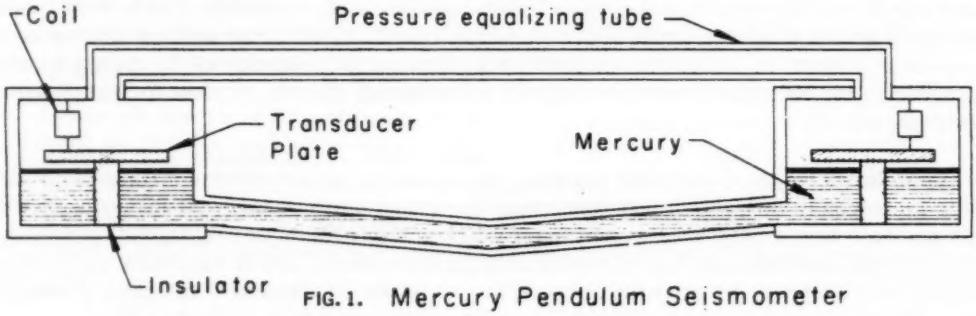


FIG. 1. Mercury Pendulum Seismometer

The wells are interconnected by means of a second tube to equalize the pressure of the nitrogen gas which is substituted for air to reduce oxidation of the mercury. A transducer in the form of a 5-mc carrier current variable capacitance discriminator circuit is mounted within each well. The variable capacitor is formed between the mercury surface and a fixed plate mounted above the mercury. Since movement of the mercury in the tube increases one gap and decreases the other, the rectified outputs of the two transducers are connected in phase opposition. Changes in the level of the mercury resulting from the relative expansion of mercury and the tube are thus cancelled.

In this first experimental model, the tube is made of plastic

material 22 meters in length with 0.95-cm inside diameter, and a diameter of the wells at each end of 10 cm. The differential output passes through a band-pass filter to a high-impedance input recorder. The band-pass filter has a high-frequency attenuation of 12 db per octave at a 5-second period, and a low-frequency attenuation given by a single-stage RC filter with 20-second time constant. The low-frequency cutoff serves to reduce the response to diurnal temperature tilts of the ground and tidal movements.

Copies of seismograms of the Kurile Islands' earthquake (10 July 63, 05:22:57 GMT, Magnitudes - 5.6) as recorded at Pasadena with the mercury seismograph having a period of 72 seconds and the standard Press-Ewing seismograph with a period of 15 seconds are reproduced in Fig. 2. The lines drawn on the mercury record are 2 minutes apart. It is clear that the mercury pendulum has a better response to seismic waves with periods greater than ½ minute.

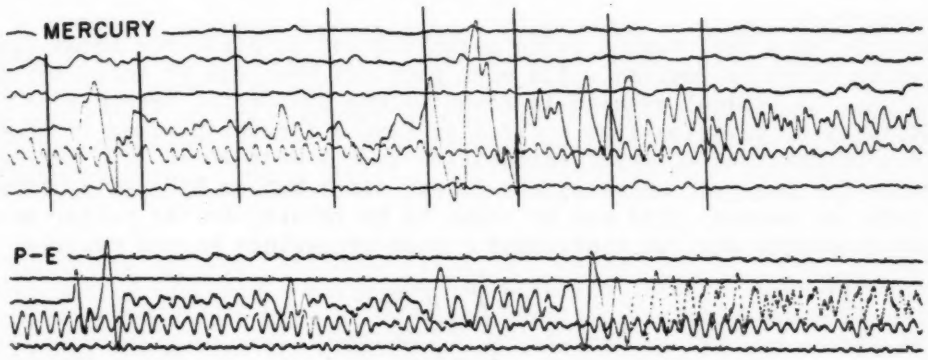


FIG. 2.

The mercury seismograph has the following advantages over conventional long-period instruments: (a) stable period and damping characteristics, since these depend only on the dimensions of the tube and wells; (b) reduced local noise response owing to the long length of the tube. Local tilts of the pier resulting from changes in moisture content of underlying rock and local temperature fluctuations disturb long-period pendulums mounted at a single point to a greater extent; (c) owing to the small enclosed space above the mercury in relation to its length, convection currents of the nitrogen are negligible in their effects upon the pendulum; (d) absence of a galvanometer which, at long periods, is always a nuisance; (e) the instrument can be operated satisfactorily for longer periods at higher magnifications than conventional pendulum seismographs.

Dr. Benioff's research is sponsored by AFOSR Grant AF-AFOSR-62-355 in support of the Advanced Research Projects Agency's Vela-Uniform Program.

Abel's integral equation, or "when is a solution not a solution"

HENRY E. FETTIS, *Applied Mathematics Research Laboratory*, ARL

An equation of considerable importance in many physical problems is the one known as the Abel Integral Equation. In its most general form it may be written

$$(1) \qquad g(x) = \int_0^x \frac{f(y)dy}{(x-y)^{\alpha}}$$

where α is a real number lying between 0 and 1, g(x) is a known function and f(y) is desired. (In most physical problems it turns out that $\alpha = \frac{1}{2}$.) A typical example is found in the problem of determining the intensity of emission from a circular source through plasmas or other media by means of observed intensities on a linear scale. In such a system the observer measures the linear distribution N(Z) at a distance Z from the source; this may be shown to be related to the radial emission intensity G(r) at a distance r from the origin by the equation

$$(2) \qquad N(Z) = 2\int_Z^{r_0} \frac{G(r)rdr}{\sqrt{r^2 - Z^2}}$$

The change of variables $y = r_0^2 - r^2$, $x = r_0^2 - y$ brings this equation into the form of Eq. 1.

The mathematician has long known that the explicit solution of Eq. 1 is

$$(3) \qquad g(x) = \frac{\sin(\alpha\pi)}{\pi}\left[\frac{\partial}{\partial x}\int_0^x f(y)(x-y)^{\alpha-1}dy\right]$$

Eq. 3 can also be written in a slightly different form, namely

$$(4) \qquad g(x) = \frac{\sin(\alpha\pi)}{\pi}\left[x^{\alpha-1}f(o) + \int_0^x f^1(y)(x-y)^{\alpha-1}dy\right]$$

To the mathematician, either (3) or (4) is an acceptable solution to (1); to the physicist neither is acceptable. In a physical problem, f(y) is usually defined by experimentally determined numerical data. Thus, to employ the solution in the form (2), we would have to integrate this experimental data and then differentiate the results numerically. With Eq. (3), the situation is equally bad, since we would first have to obtain derivatives of f(y) numerically and then integrate the results. In addition, there would be the problem of integrating numerically a function with a singularity at one point. The latter problem is actually the lesser one, since it may be avoided by a suitable change in the variable of integration. To circumvent the first one, however, we would need a form of the solution in which only f(x) appears. Such a form can be found if a rather shrewd integration by parts is carried out. The result is

$$(5)\quad g(x) = \frac{\sin(\alpha\pi)}{\pi}\left[x^{\alpha-1}f(x)+(1-\alpha)\int_0^x \frac{f(x)-f(t)}{x-t}\,(x-t)^{\alpha-1}\,dt\right]$$

At first glance, it would seem that little gain has been made since the singularity apparently is stronger than in the previous two forms. A closer examination, however, indicates that the situation is no worse than it was previously. To justify this conclusion, we must naively assume that, even though we can not obtain it explicitly, the expression $\frac{f(x) - f(t)}{x - t}$

does indeed approach a finite value as t approaches x, namely f'(x). With this assumption, we can now evaluate the integral involved numerically without ever knowing exactly what this limiting value is, provided our quadrature formula never takes us to the end points of the integration interval. Fortunately such formulae are available; they are known as Gaussian quadrature formulae and have the additional advantage of giving surprisingly high accuracy with a relatively few points. Further, they can be so constructed that the singular behavior of the integrand is taken care of automatically. An extensive table of these formulae has been compiled by the author for the case of $\alpha = \frac{1}{2}$, and will appear in a forthcoming issue of the periodical, "Mathematics of Computation."

FY 1964 Directors' Fund Allocation - AFCRL Commander, Brigadier General B. G. Holzman, recently announced the selection of 22 AFCRL projects for funding under the Laboratory Directors' Fund budget for FY-1964. This is a special category of funds established in 1962 which may be spent largely at the discretion of the Director. The special fund was created in response to the need for greater flexibility in the planning of research programs and the expenditure of research funds.

ELECTRON-RADIATION DAMAGE IN *ZINC SELENIDE*

Dr. B. A. KULP, *Solid State Physics Research Laboratory*, ARL

Electron bombardment of crystalline material produces vacancies and interstitials in the material. At sufficiently low temperature and electron-beam energy, isolated vacancies and isolated interstitials are formed as contrasted to clusters of defects which are formed by heavy-particle bombardment or by exposure to high temperature. Of fundamental interest is the threshold for electron-radiation damage; that is, the minimum electron energy sufficient to cause displacement of an atom from its lattice point. In ZnSe, the threshold for electron-radiation damage is 240 keV. An electron with this energy can transfer a maximum of 8.2 eV to a selenium atom, and 10 eV to a zinc atom. At this time it is not known whether the zinc or selenium atom, or both, are being displaced by these electrons, because only one threshold has been observed.

Bombardment at 85°K with electrons exceeding the threshold results in the production of a broad fluorescence band labeled B are shown in Fig. 1. There is a linear dependence of the intensity of B on the number of electrons striking the crystal. The proportionality constant is dependent on the electron-beam energy. The broad fluorescence, B, can be resolved into two bands as shown in the figure. The peaks are at 5460 and 5880Å. Both of these bands have been found in "as-grown" crystals, but have not been observed to appear together except in electron-bombarded crystals. The explanation for this lies in the fact that, if the crystals are exposed to 165°K temperatures after bombardment, the damage anneals completely and it is necessary to bombard the crystals again at energies above the threshold and at temperatures below 140°K to produce the above fluorescence once again.

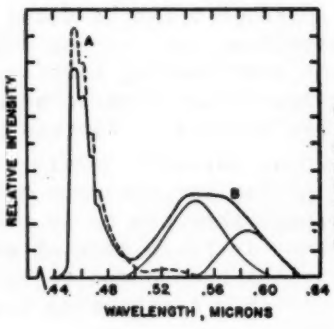


FIG. 1. Fluorescence spectra of ZnSe (A) before and (B) after bombardment at 85°K with 500-keV electrons. Spectra taken at 80° excited with 275-keV electrons 5 $\mu A/cm^2$.

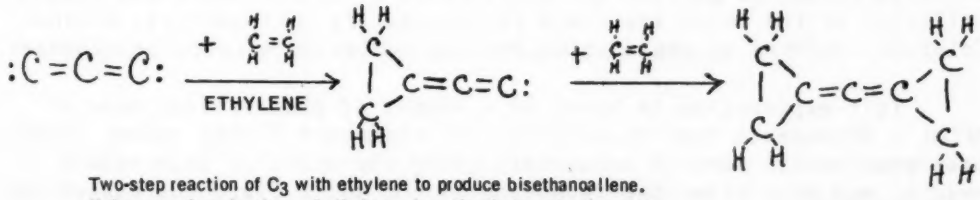
The kinetics of the annealing process are being studied currently to determine if the defects responsible for the two overlapping fluorescences are isolated vacancies and isolated interstitials, or whether the center is a complex one such as two vacancies coupled together, or a vacancy and an interstitial coupled together.

C=C=C=Comet Chemistry

Dr. ALFRED WEISSLER, *Directorate of Chemical Sciences*, AFOSR

The chemical make-up of comets, long a challenge to man's curiosity, was explained in part by the spectroscopic discovery of the C_3 molecule in comet atmospheres. Although this discovery was made over 20 years ago, it has not been exploited because of the difficulties in simulating the comet's very-high temperatures and low pressures, which are needed for studying the reactive :C=C=C: species.

Under an AFOSR grant at Pennsylvania State University, Dr. P. S. Skell has devised a laboratory scheme which enables him to investigate this field. High-purity graphite is exploded by a powerful electric discharge, inside an evacuated glass tube, producing carbon vapor rich in C_3 molecules at a temperature of 3600°C. At the low pressures used (about one ten-millionth of an atmosphere), these molecules can travel without collisions until they hit the wall of the glass tube. There they encounter the substance with which they are to react, such substance having previously been frozen onto the wall. The products of the reaction are pumped off and analyzed by gas chromatography.



Two-step reaction of C_3 with ethylene to produce bisethanoallene. Using propylene in place of ethylene gives the three space-isomers of dimethyl-bisethanoallene.

When C_3 was allowed to react with frozen ethylene in this apparatus, the major product was found to be bisethanoallene, a previously unknown material containing a small ring at each end of the molecule. If frozen propylene was used instead of ethylene, three stereoisomers of dimethyl-bisethanoallene were formed in relative amounts which showed that the reaction was a two-step process. Results such as these help to clarify the reactions which may be taking place in comet atmospheres.

This research was motivated by a desire to understand the mechanisms of preparative organic chemistry which involve reactive carbene intermediates; C_3 is a dicarbene. Even so, here as in many other cases, the fruits of fundamental research by outstanding chemists aid the Air Force to meet the challenge of understanding and operating in the new aerospace environment.

MECHANISM OF LOOP PROMINENCES

FRANK ORRALL, *Space Physics Laboratory*, AFCRL

A loop prominence is perhaps the most spectacular show produced by the sun. This huge elliptical loop of dense plasma rises to about 70 thousand km into the solar atmosphere. With time-lapse motion-picture photography, we see that the relatively dense plasma seems to cascade down from the top of the loop, following a well-defined course. The display may last for several hours.

Only when the loop prominence occurs at the edge of the solar disk do we see this event in full splendor--and this circumstance is rare, occurring perhaps once a year at best. It is viewed with a special telescope known as a coronagraph which creates an artificial solar eclipse by covering the disk of the sun. With the coronagraph, we also see many unstructured prominences--giant surges which seem to erupt above the solar disk--but the mechanism that results in the structured-loop prominences is quite different from ordinary prominences. In a paper recently presented at a Symposium on the Physics of Solar Flares in Washington, D.C., Frank Orrall of AFCRL and John Jefferies of the Joint Institute for Laboratory Astrophysics, Boulder, Colorado, offered an explanation for the mechanism of loop prominences.

This explanation is based on a number of observations made at AFCRL's Sacramento Peak Observatory and elsewhere during recent years. Loop prominences seem to occur only after the onset of solar-flare events, and only after the intensity of the solar flare has passed the maximum. Solar flares (not to be confused with prominences) are huge explosions on the visible surface of the sun. These flares inject a great flood of high-energy particles into the solar corona and into space, and these sometimes reach the earth's atmosphere where they disrupt radio communications. Although loop prominences form above solar flares, not all flares produce loop prominences. The loop itself outlines magnetic lines of force, but occurs only along the innermost lines.

It has been difficult to tie these observations together into a meaningful model. The primary difficulty involved explaining the source of the energy and mass needed to sustain the loop prominence for several hours--that is, just how are the charged particles fed into the loop? One view was that the energetic particles are generated at the visible surface (photospheric level) of the sun by the solar flare and move up the magnetic lines of force; but this view could not account for the sustained lifetime of the prominence along an inner line of force. Another view was that the loops are formed from the condensation of surrounding coronal gases; but this view could not account for the trans-

fer of mass and energy to the loops across the magnetic field. Furthermore, coronal condensation would be too slow to account for the high radiative losses of the loop system.

Orrall and Jefferies, in their paper, suggest the following mechanism: solar flares inject charged particles into the total magnetic field where they become trapped. Near the poles of the magnetic field, energetic particles from the outer-field lines drift to the inner lines. At the top of the loop of the inner lines of force, density and temperature increase as more and more particles drift across from the outer to the inner lines of force. The hot, dense regions at the top of the loop cool by radiation and expansion to observed loop-prominence temperatures. The process continues throughout the lifetime of the loop prominence in a pulsating, irregular fashion. Because the thermalization process begins at the top of the loop and moves downward where it seems to dissipate, the illusion is created that the plasma is cascading down from the top of the loop.

The Restricted Three-Body *PROBLEM*

Major BARNETT R. AGINS, USAF, *Applied Mathematics Division*, AFOSR

One of the most celebrated problems of dynamics is the three-body problem. Recently, under AFOSR sponsorship, Dr. V. Szebehely published a comprehensive review of the problem, its history and its future.(1) In its most general form, the problem may be stated as follows: given three particles that are free to move in space under the influence of a given force field and to initially move in any manner, determine their subsequent motion.

The problem is of specific interest in celestial mechanics, which is devoted to the motion of celestial bodies. Space mechanics is a branch of celestial mechanics which studies the motion of artificial celestial bodies. In this context, the force field is Newtonian gravitation, in which the attraction between pairs of particles is proportional to the product of the masses divided by the square of the distance between them.

One of the consequences of this law is that, if the mass of one of the three bodies is very much less than the masses of the others, its influence on either of the two "heavy" bodies is considerably less than their mutual interaction. Under these conditions, the motions of the

"heavy" bodies may be examined, ignoring the lighter body; then an attempt may be made to analyze the motion of this body as influenced by the predetermined motion of the other two. This approach is referred to as the restricted three-body problem.

An example is a problem involving the earth, the moon and a 6000-kilogram space probe. The mass ratios would be approximately $100:1:10^{-19}$; thus the force between the earth and the moon is 16 orders of magnitude greater than the force between the probe and either of the primaries. It is clear that problems in space mechanics always belong to the category of the restricted problem, since the vehicle does not influence the motion of the primaries.

Research on this problem has been going on for centuries. The major contributors to the restricted three-body problem were Euler, Jacobi and Poincare. Subsequent refinements were made in this century, and the high-speed digital computer has made it possible to achieve useful, numerical results.

Euler's work was essentially computational. In 1760, he gave the solution of the two fixed-force center problem, in which two fixed masses act on a third body according to Newtonian gravitation. The direct application of this problem is limited, since fixed-force centers do not occur in space mechanics; however, its indirect applications are numerous since it can be solved analytically. For example, Euler's solution can be used as a reference orbit for general perturbation calculations. The value of a reference orbit is determined by how closely it approximates the actual solution and by how simple it is. solution qualifies, since it yields analytical expressions; unfortunately, the solution becomes quite complicated since it involves elliptic functions. The alternative, Enke's method, though far simpler, considers only one mass, while Euler's considers both.

Another application of this work of Euler is in regularization. The restricted problems possess two finite singularities produced when the distance between the "small" mass and either of the "large" masses approaches zero. These singularities introduce fundamental difficulties into the solution process. Euler introduced a coordinate transformation which, when used in the restricted problem, eliminates the singularities, or "regularizes" the problem. Regularization is of extreme importance in space mechanics. The computation of trajectories which connect two singularities (e.g., earth-moon) is a major problem. As the distance between the vehicle and one of the primaries approaches zero, the precision of computation must be increased to maintain the desired accuracy. Regularization reduces the complexity of computation. In another context, regularization appears to be the only way to establish the totality of orbits, necessary in the selection of feasible paths for space missions.

Euler's other contribution to the restricted problem was made in 1772 in connection with his lunar theories. By a lunar theory, we mean a calculable solution to the determination of the motion of the moon. (Euler's method was sufficiently practical so that the British Admiralty's lunar tables were computed by it.) This work of Euler's was the first major direct contribution to the restricted problem. He also introduced a rectangular rotating coordinate system subsequently utilized by such contributors as Jacobi and Hill.

Jacobi (1836) discovered that the circular restricted problem possesses an integral when rotating coordinates are used. By an integral we mean a function which is a constant along an orbit. In the Jacobi integral, the function connects the speed of the third body with its position, and permits certain general qualitative statements regarding the motion without actually solving the equations of motion. This is of particular importance when applicable to an "insoluble" dynamical problem.

The general form of the integral is:

$$v^2 = f(x,y) - C$$

where v is the speed relative to the rotating coordinate system, $f(x,y)$ is a given function of position in the same coordinates, and C is a constant. Given the function, a point on the trajectory and the speed at that point, C is fixed for the trajectory and cannot be changed except by the application of some force, such as thrust. Since v^2 can never be negative, the vehicle can only penetrate those regions of space for which v^2 is nonnegative; the boundary of those regions is $v^2 = 0$. These boundaries are called zero-velocity curves or Hill curves, since Hill (1878) exploited them, and showed that the earth-moon distance is bounded from above. Besides defining boundaries, zero-velocity curves can be used as reference orbits under certain conditions.(2)

The Jacobi integral can also be used in controlling computation errors. The initial conditions determine the constant C, and any orbit calculation must maintain this value. Since analytic solutions are not available for orbits of prime interest, computation controls such as the invariance of C are of extreme importance in digital-computer solutions.

Poincare's famous work on celestial mechanics was completed in 1899. His emphasis was on the qualitative methods, rather than on the quantitative methods of Euler and Jacobi. Qualitative methods are dominant in questions of stability, periodicity, existence, integrability and the totality of possible orbits.

It has been pointed out that the most practical engineering aspects of space mechanics are also the most abstract problems of

qualitative dynamics. The basic problem in system engineering is the selection of a trajectory which satisfies the mission requirements, i.e., to establish orbits with regard to launch windows, power availability, accuracy, range safety, etc. It is necessary to know the totality and existence of orbits for this purpose. It can happen in principle as well as practice that a certain set of mission requirements cannot be met since no orbit exists which will perform the mission under the given conditions. Existence problems are the most sophisticated of those in dynamics, yet the most practical in systems engineering.

Periodic orbits are of fundamental importance both practically and theoretically. Poincare suggested that any orbit can be approximated by a periodic orbit and perturbation methods applied. Use as reference orbits is limited by lack of closed form analytical solutions. Periodic orbits are of practical interest since such orbits about the moon and earth, with close approaches to the primaries, are very desirable for photographic and manned lunar explorations. These orbits can be studied by Poincare's methods.

The question of stability of orbits is important to the systems engineer, since those trajectories which are extremely sensitive to accuracy of burnout require extra guidance provisions.

Integrability questions are important since, if under certain conditions the restricted problem is integrable, solutions can be obtained and considerable progress achieved in space mechanics.

Reducibility involves reduction of the order or number of the dynamical equations. Birkhoff (1915), following Poincare, used the analogy between the restricted problem and the steady nonpotential flow of an incompressible fluid to present the third-order system in a most interesting way. The generalization of the Poincare-Birkhoff analogy may well constitute one of the most promising areas of research.

With this historical background, let us now look at the major areas of space mechanics: orbit prediction, determination, modifications and selection.

Orbit prediction is the precomputation of trajectories in a given force field for a certain set of initial conditions. The principal approach has been through matched conic sections. One assumes that the satellite follows a Keplerian orbit under the influence of one primary, then a Keplerian orbit about the other primary. The main problem is in the transition region where the two-body approximation fails to represent the motion. Also, there appears to be some influence of one primary even when the satellite is close to the other primary. Some results have been obtained by Kevorkian.(3)

The treatment of the central problems is along two well-established lines -- special and general perturbation techniques. Special perturbations involve establishment of trajectories for given sets of initial conditions, and the methods of Cowell (1910) and Enke (1857) are used. Both methods require considerable computer time, and are dependent for accuracy upon the proper selection of reference orbits and a knowledge of the totality of orbits.

Orbit determination is the establishment of trajectories from observational information and a knowledge of the force field. From one set of observations, initial conditions are deduced and orbit-prediction techniques employed. Additional observations are compared with the prediction and the prediction is revised to fit the data. An important step is differential correction computation. The aim is to obtain accurate trajectories with a minimum of observations.

Orbit modification is the changing of an established orbit. Since this can be achieved only by a change in the total force field, the question arises only when some form of thrust is available. The problem here is to find optimum transfer orbits with respect to such criteria as thrust, time, etc.

The question of orbit selection is of primary importance to the Space Systems engineer. Any trajectory is possible with the expenditure of sufficient thrust. But, with limited fuel, it is paramount that the totality of "free" trajectories be known.

To date, all the approaches have been based on matched conic-section techniques. A great deal of work has been done, both theoretically and experimentally, in the sense of computation of a large number of orbits. There are still many questions including one concerning the existence of orbits which are not conic sections, such as figure-eight orbits.

There is still much to be done on the restricted problem. Szebehely points out that the discovery of a new integral would accelerate the "solution" of many problems in space mechanics. This step is, unfortunately, highly improbable in the near future. More realistically, the future of the restricted problem may lie in:

(1) Regularization studies

(2) Establishment of the totality of possible orbits

(3) Introduction of new reference orbits

(4) Derivation of new approximate solutions

(5) Development of general perturbation techniques

The Applied Mathematics Division is currently sponsoring a number of investigations in the area of celestial mechanics, including both general studies and research on specific problems. In addition, projects in such areas as numerical integration and approximation theory provide support for computational methods in celestial mechanics.

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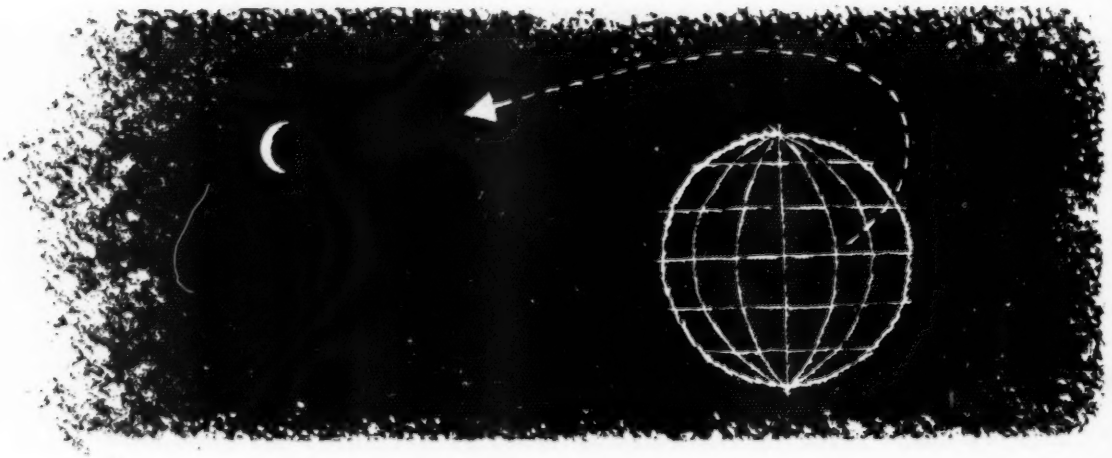


DESIGNING LASERS by COMPUTER

Captain TOM G. PURNHAGEN, USAF, *Microwave Physics Laboratory*, AFCRL

In a general, qualitative way we know what is needed to improve the efficiency of lasers. Laser efficiency usually increases if we: increase the length of the laser rod, increase the radius of the rod, increase its doping density, decrease the reflectivity of its polished ends, increase pumping energy, and decrease the pumping pulse decay time constant. All this has been learned over the past few years through experimental studies (often by simple trial and error) carried out by an estimated 500-odd laboratories involved in laser research.

But this knowledge does not permit us to sit down and design an optimum laser. Too many relevant parameters and too many interrelationships are only dimly understood. So the laser designer simply makes a number of assumptions, assembles a laser based on these assumptions, and tests simultaneously both the validity of his assumptions and the laser device. In a paper recently prepared by Capt. T. G. Purnhagen of AFCRL and J. Lubelfeld of the Air Force Institute of Technology, a computer program is described which permits the designer to approximate optimum efficiency prior to the actual physical construction of the system.

The computer program is concerned only with pulsed, four-level laser systems. The efficiency of such systems is first defined as a product of six subefficiencies, each associated with one of the loss mechanisms of the system. These subefficiencies are:

1) Lamp efficiency: the ratio of the output energy of a given pumping source which lies within a speficied range of wave length to the total input energy of that source.

2) Geometrical efficiency: the ratio of the photon energy which enters the laser rod to that produced by the pumping source, again within a specified wave-length range.

3) Capture efficiency: the ratio of the energy transferred to active ions to the total energy entering the rod.

4) Relaxation efficiency: the ratio of energy radiated in the desired transition to the total energy stored in the pumping band.

5) Radiation efficiency: the ratio of the energy which enters the coherent field to the total energy involved in the transition from the metastable state to the terminal state.

6) Optical efficiency: the ratio of useful output energy to the energy which enters the coherent field.

Equations which relate these subefficiencies to physically measurable parameters have been derived. From these, a program has been written in a modified FORTRAN language for the IBM-1620 computer for the design of a neodymium-doped glass laser oscillator. The program, of course, requires that a number of assumptions and approximations be made. It must be assumed, for example, that the laser crystal is a perfect cylinder of evenly doped homogeneous material, and that the crystal is evenly illuminated by the pump source. The program also assumes that the total output is useful energy; in other words, it does not distinguish between different modes. Other assumptions must be made with respect to the energy states of the atom population in the material. Approximations must be made in the computer program with respect to graphical integrations, representation of spectra and threshold times.

The system parameters are grouped into two general classes: constants which cover lamp efficiency, absorption cross section, laser output wave length, and laser rod length, radius, end mirror absorptives, and so on. Once the constants are determined, a number of problems can be run with different values of the independent variables without changing the constants. The values of the constants can, of course, be changed when necessary by simply rerunning a portion of the program.

The program has been run to test the validity of the model--that is, to determine whether results are consistent with previous physically observed performance of lasers and laser materials. Results are in good agreement with these observations.

participation in GEMINI program

LOUIS C. BLOCK, *Optical Physics Laboratory*, AFCRL

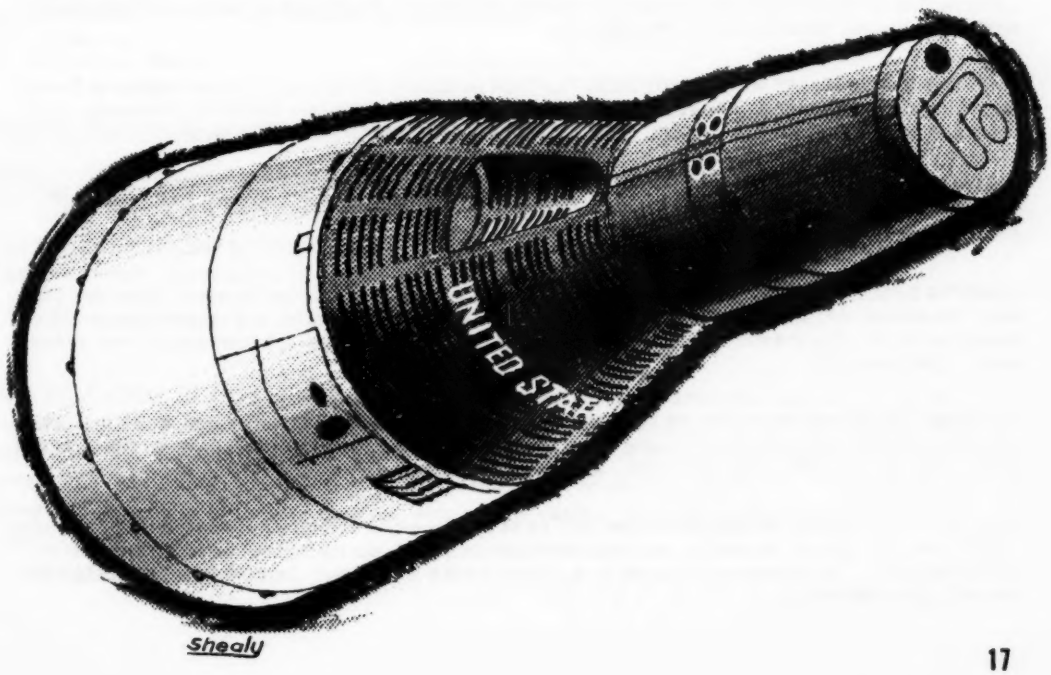
When the two-man Gemini space flights take place in late 1964 or early 1965, the project astronauts will perform a series of optical experiments designed by AFCRL. Spectral and radiometric measurements (measurements of radiant energy) will be made of the earth and sky backgrounds and of the radiation emitted by a missile during launch and while in flight. Measurements will also be made of radiation emitted by an object ejected from the Gemini vehicle, and by individual celestial bodies such as the moon, a star or a planet. AFCRL will design the experiments, integrate the pay load, calibrate the instrumentation, and perform the data reduction and analysis.

A special handbook of instructions for the Gemini astronauts who will conduct the experiments is being prepared. The AFCRL-designed instrumentation for the flights will include a radiometer that will cover the region from 2000 angstroms to 20 microns in 30 discrete bands, an interferometer that will cover the region from 1 to 15 microns, and an interferometer for the region from 8 to 12 microns. The latter instrument will include a helium-cooled detector, and will be used to measure the spectral distribution of the radiation emitted by the ejected target.

Two methods will be used to return the experimental data to earth from the orbiting vehicle. A magnetic tape recorder which, because of space limitations, has only 56 minutes of available recording time, will be carried on the vehicle and recovered after it returns to earth. "Real-time" transmission of data to ground stations will be made when the vehicle is over a ground station.

The flights are expected to provide accurate spectral and radiometric information because the measurements will be made above the earth's atmosphere. Atmospheric attenuation reduces the accuracy of ground-based measurements. The degree of actual improvement of the Gemini-vehicle measurements over the ground measurements will be obtained by a comparison of measurements made in the 2.2-micron region.

The experiments are being planned and are under the direction of Louis C. Block of AFCRL. John J. Lovett, also of AFCRL, is assisting him in this program.



Schedule of Scientific Symposia

THIRD CONFERENCE ON THE EXPLODING CONDUCTOR PHENOMENON, 10-12 Mar 64 at Boston, Mass. Sponsor: Air Force Cambridge Research Laboratories (AFCRL). For information contact Dr. W. G. Chace, AFCRL (CRZCM), Tel: Area Code 617, CRestview 4-6100, Ext. 2602. UNCLASSIFIED

SEMINAR ON NONLINEAR PARTIAL DIFFERENTIAL EQUATIONS IN MATHEMATICAL PHYSICS, 20-23 Apr 64 at New York University, New York, N Y. Cosponsors: AFOSR, Army Research Office (ARO), American Mathematical Society (AMS). For information contact Dr. R. G. Pohrer, AFOSR (SRMM), Tel: OX 6-5248. UNCLASSIFIED

FOURTH RARE-EARTH RESEARCH CONFERENCE, 22-25 Apr 64 at Phoenix, Ariz. Sponsor: AFOSR. For information contact Lt Col M. D. Sprinkel, AFOSR (SRC), Tel: OXford 6-8705, or Program Director, Dr. LeRoy Eyring, Dept of Chemistry, Arizona State University, Tempe, Ariz. UNCLASSIFIED

SYMPOSIUM ON APPLIED MATHEMATICS & MECHANICS IN HONOR OF THEODORE VON KARMAN, 11-14 May 64 at Washington, D. C. Cosponsors: AFOSR and Society for Industrial & Applied Mathematics. For information contact Maj B. S. Morgan, Jr., AFOSR (SRMA), Tel: OX 6-1302. UNCLASSIFIED

FOURTEENTH MRI SERIES SYMPOSIUM, "QUASI OPTICS," 8-10 Jun 64 at Statler Hilton Hotel, New York, N Y. Cosponsors: AFOSR, ARO, Office of Naval Research (ONR). For information contact Lt Col W. C. Athas, AFOSR (SREE), Tel: OXford 6-3671. UNCLASSIFIED

INTERNATIONAL CONFERENCE ON PHYSICS & CHEMISTRY, 21-26 Jun 64 at Brown University, Providence, R.I. Sponsor: AFOSR. For information contact Lt Col M. D. Sprinkel, AFOSR (SRC), Tel: OXford 6-8705, or Prof H. E. Farnsworth, Brown University. UNCLASSIFIED

INTERNATIONAL BIOPHYSICS MEETING, 22-27 Jun 64 at Paris, France. Cosponsors: AFOSR, International Organization for Pure & Applied Biophysics, and National Academy of Sciences. For information contact Capt B. D. Stollar, AFOSR (SRLA), Tel: OXford 6-4181. UNCLASSIFIED

INTERNATIONAL CONFERENCE ON PHOTOSENSITIZATION IN SOLIDS, 22-24 Jun 64 at Illinois Institute of Technology, Chicago, Ill. Cosponsors: AFCRL, ONR, Space Physics Laboratory, and Illinois Institute of Technology, For information contact T. K. Mukherjee, AFCRL (CRFE)', Tel: Ext. 3227. UNCLASSIFIED. Attendance by invitation only.

SYMPOSIUM ON QUANTITATIVE BIOLOGY, Jun 64 at Cold Spring Harbor, N Y. Cosponsors: AFOSR and Cold Spring Harbor Laboratory of Quantitative Biology. For information contact Capt B. D. Stollar, AFOSR (SRLA), Tel: OXford 6-4181. UNCLASSIFIED

LEARNING & ASSOCIATED PHENOMENA IN INVERTEBRATES, 6-9 Jul 64 at Cambridge University, Cambridge, England. Cosponsors: AFOSR, ONR, National Science Foundation (NSF), American Society of Zoologists, and British Association for the Study of Animal Behavior. For information contact Dr. R. V. Brown, AFOSR (SRLA), Tel: OXford 6-4181. UNCLASSIFIED

1964 SUMMER RESEARCH INSTITUTE ON ALGEBRAIC GEOMETRY, 6-31 Jul 64 at Whitney Estate, Woods Hole, Mass. Cosponsors: AFOSR, NSF, AMS, North Atlantic Treaty Organization. For information contact Dr. R. G. Pohrer, AFOSR (SRMM), Tel: OXford 6-5248. UNCLASSIFIED. Attendance by invitation only.

CONCENTRATED VORTEX MOTIONS IN FLUIDS, 6-11 Jul 64 at University of Michigan, Ann Arbor, Mich. Cosponsors: AFOSR, ONR, NSF, National Aeronautics and Space Administration (NASA), and International Union of Theoretical and Applied Mechanics. For information contact Maj W. B. Terrell, AFOSR (SREM), Tel: OXford 6-3425. UNCLASSIFIED Attendance by invitation only.

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